The nature of the X-ray source in NGC 4151

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Abstract. Analysis of broad-band X/γ-ray spectra of NGC 4151 shows that the data are well modelled with an intrinsic spectrum due to thermal Comptonization with temperature ~ 50 keV and X-ray spectral index $\alpha \sim 0.4$–0.7. The variable X-ray spectrum pivots at ~ 100 keV, which is consistent with the observed approximatly constant γ-ray spectrum. The observed UV/X-ray correlation can be explained by two specific models with reprocessing of X-rays by cold matter. The first one is based on reemission of the X-ray flux absorbed by clouds in the line of sight. The second assumes reprocessing of X-rays and γ-rays by a cold accretion disk with a dissipative patchy corona.

1. Introduction

NGC 4151 is a nearby Syfert 1.5 galaxy. Its X-ray spectrum is highly variable in both the 2–10 keV flux and the 2–10 keV spectral index (e.g. Yaqoob et al. 1993). The X-ray flux shows a good correlation with the UV flux (Perola et al. 1986). The spectrum is consistent with optically-thick thermal Comptonization rather than highly-relativistic optically-thin one, which is characteristic for less variable spectra of Syfert 1's. We consider here the origin of the variability of NGC 4151.

2. Spectral variability

Zdziarski, Johnson & Magdziarz (1996) analyzed the broad-band X/γ-ray spectra of NGC 4151 from contemporaneous observations (Fig. 1), and they found that the data are well modelled with an intrinsic spectrum due to thermal Comptonization (Titarchuk & Mastichiadis 1994). The X-ray energy spectral index changes from $\alpha \sim 0.4$ to 0.7, and the temperature stays at ~ 50 keV. The spectra show no Compton reflection component. Other observations by OSSE up to Dec. 1993 also show that the observed spectra and fluxes are roughly constant and can be described by thermal Comptonization at $kT \simeq 60$ keV. The pattern of spectral variability can be described by varying X-ray power law pivoting at ~ 100 keV (cf. Fig 1). The spectrum breaks at that energy permitting the γ-ray flux to stay approximately constant.

We also reanalyzed X-ray observations from *IUE* / *EXOSAT* campaigns in 1983 Nov. 7–19 and 1984 Dec. 16–1985 Jan. 2 (Perola et al. 1986). Refitting of the *EXOSAT* data with a power law and a constant soft excess component resulted in a correlation close to linear between the absorption-corrected EF_E at 5 keV and at 8.5 eV (from *IUE* de-reddened observations; Ulrich et al. 1991), which values are comparable.

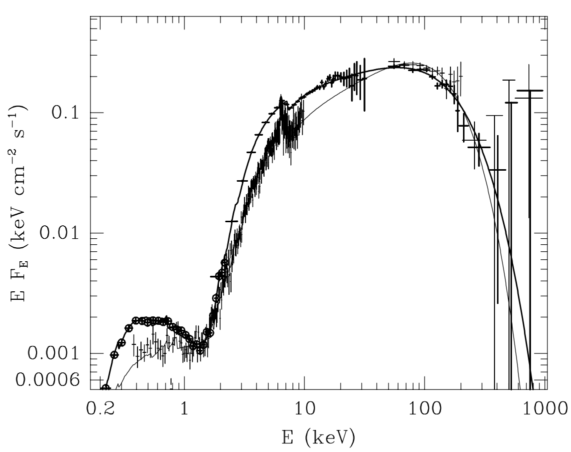

Fig. 1. Thick symbols show the spectrum observed by *GRO*/OSSE, 1991 June 29–July 12 and by *Ginga* (Yaqoob et al. 1993) and *ROSAT* (marked by circles, Warwick, Done & Smith 1995), 1991 May 31–June 1. Thin symbols show the spectrum observed by OSSE, 1993 May 24–31, and by *ASCA*, 1993 May 25. The spectra are described by thermal Comptonization models with $kT = 66$ keV, $\alpha = 0.65$ and $kT = 47$ keV, $\alpha = 0.44$ (thick and thin solid curves respectively) absorbed by an ionized medium, and with addition of a soft excess (Zdziarski, Johnson & Magdziarz 1996).

3. The variability models

The UV/X-ray correlation can be explained by two specific models with reprocessing of X-rays by cold matter (Zdziarski & Magdziarz 1996). The first one is based on reemision of the X-ray flux absorbed by Thomson-thin clouds in the line of sight. The clouds are dense enough for almost complete termalization. The model predicts no Compton reflection which is consistent with the broad-

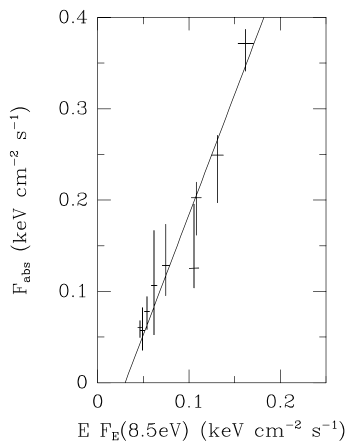

Fig. 2. Comparison of the transmission model prediction with the *IUE*/*EXOSAT* data. The crosses give the flux F_{abs} absorbed by the cold matter obtained from *EXOSAT* data, and EF_E(8.5eV) from *IUE*. The solid line gives EF_E(8.5eV) as a function of F_{abs} from the transmission model.

band spectra. The second model assumes reprocessing of X-rays and γ-rays by a cold, optically-thick accretion disk with dissipative patchy corona. The absorbed radiation is reemitted locally in UV as a blackbody. The homogeneous corona model is ruled out because the hardness of the X-ray spectrum implies that the plasma is photon starved. Our second model predicts Compton reflection marginally allowed by the observations. Both models satisfy the energy balance and provide good fits to the X/γ-rays and UV data.

The transmission model (Fig. 2) predicts: $F_{UV} = fF_{abs} + F_0$ where F_{UV} is the integrated UV flux, $F_0 = 0.05$ keV cm^{-2} s^{-1} is a residual UV flux, and the factor $f = 0.60$ takes into account incomplete covering of the X-γ source by the clouds as well as an efficiency of the absorbed flux conversion into the blackbody continuum. We determined the temperature of the absorber as $kT \simeq 3$ eV from the average observed spectral index in the UV between 8.5 and 7.2 eV (α = -0.15; Perola & Piro 1994). The typical column density of a cloud in the partial covering absorber is $N_H \simeq 10^{23}$ cm^{-2} with the typical covering factor of $\simeq 0.5$. The size of a single cloud is $r_c \lesssim 10^7$. The average size of the entire absorber is $\sim 10^{14}$ cm, which satisfy the limit $r \lesssim 10^{15}$ cm from the relative UV/X-ray time delay (Warwick et al. 1995). The parameters of the absorber are similar to those studied by Ferland & Rees (1988) and Guilbert & Rees (1988).

In the reflection model we assume that all dissipation takes place in the corona (e.g. Svensson & Zdziarski 1994). We integrate the blackbody emission over the disk surface with the standard disk dissipation rate (Shakura & Sunyaev 1973). This relates the observed 8.5 eV flux to the total UV flux as a function of $r_S\mu^{1/2}$, where r_S is the Schwarzschild radius, and μ is a cosine of the disk inclination angle. The model predicts $F_{UV} = 2(1-A)\mu R F_{X\gamma}$, where A is an albedo for the total X-γ flux, $F_{X\gamma}$, and R is a ratio of the corona emission intercepted by the disk to the luminosity emitted outward. Compton reflection for $R < 0.5$ is consistent with the broad-band spectra. We find that all $0 < r_S < 2.4 \times 10^{12}$ cm (or equivalently $\mu R \gtrsim 0.15$) fit the UV spectral indices (Fig. 3). The value of $r_S = 1.3 \times 10^{12}$ cm (for $\mu R = 0.21$) provides the best fit to UV fluxes.

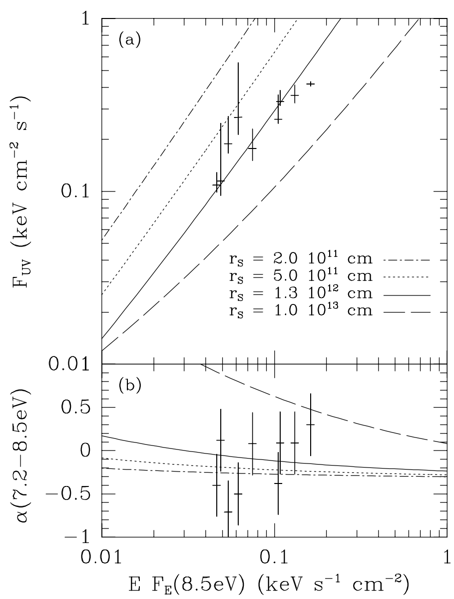

Fig. 3. Comparison of the reflection model predictions with the data. (*a*) Crosses give the total UV flux F_{UV} from reemission of the absorbed X-γ flux as obtained extrapolating the *EXOSAT* X-ray power laws to γ-rays assuming thermal Comptonization at kT = 60 keV, R = 0.5, and μ=0.42 (from *HST* observations, Evans et al. 1993). The curves relate the total F_{UV} to EF_E(8.5eV), as predicted by the disk spectrum for various Schwarzchild radii r_S. (*b*) Crosses give the UV spectral indices (Ulrich et al. 1991). Curves give the indices predicted by the disk-corona model.

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